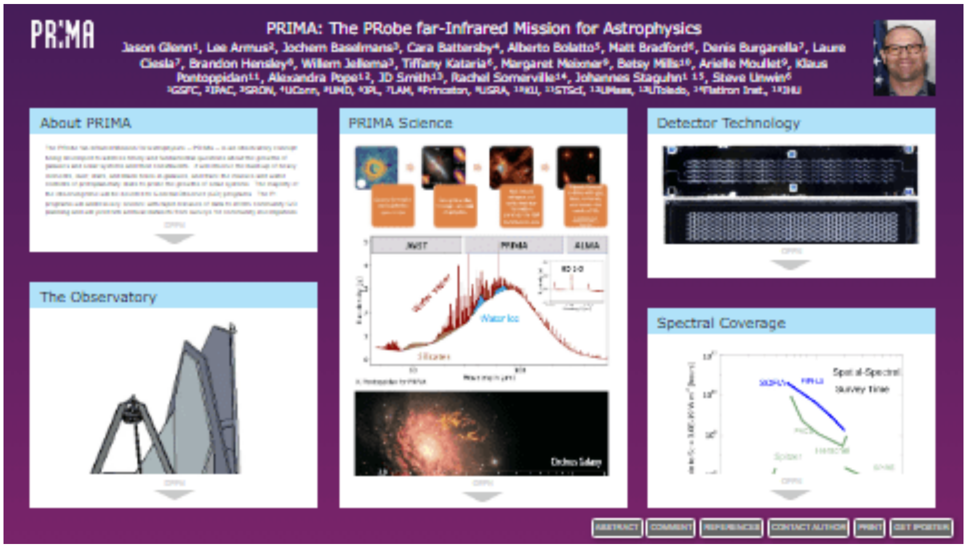
PRIMA: The PRobe far-Infrared Mission for Astrophysics



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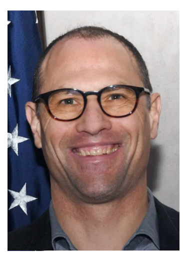

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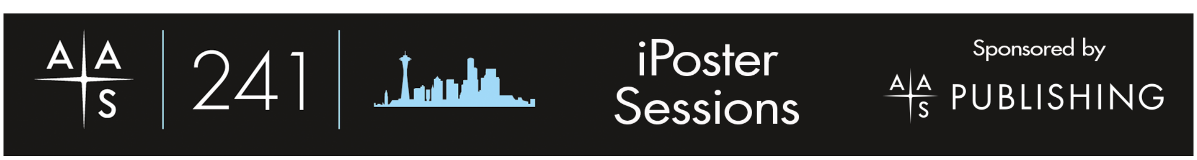
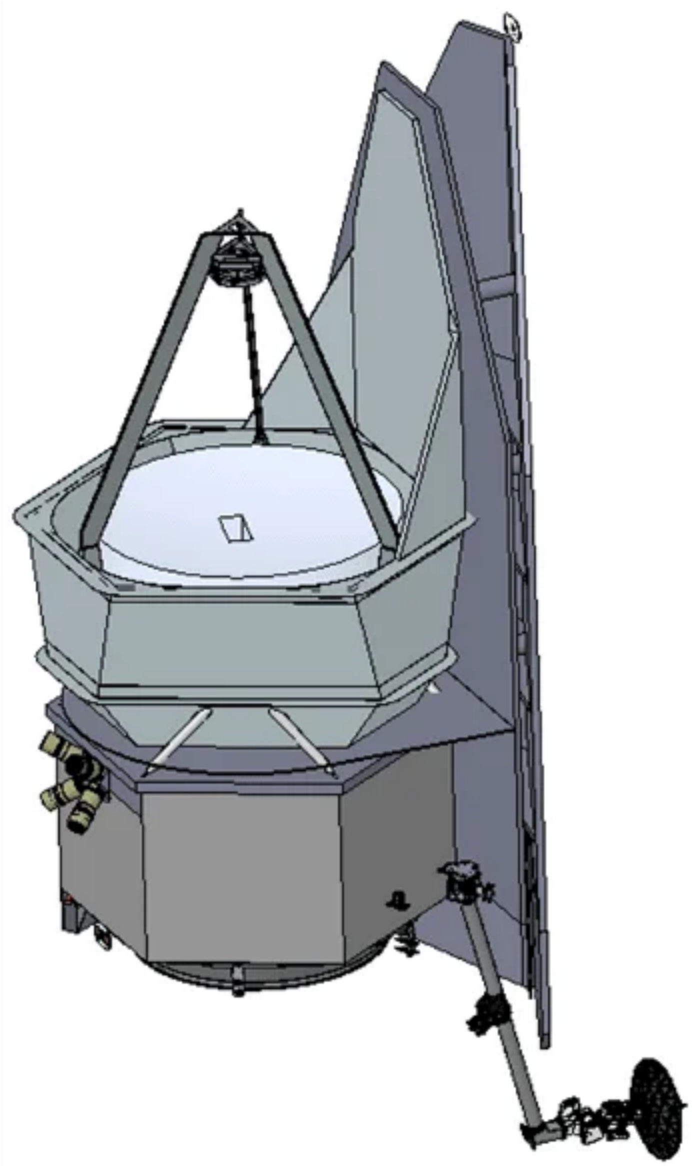


ABOUT PRIMA

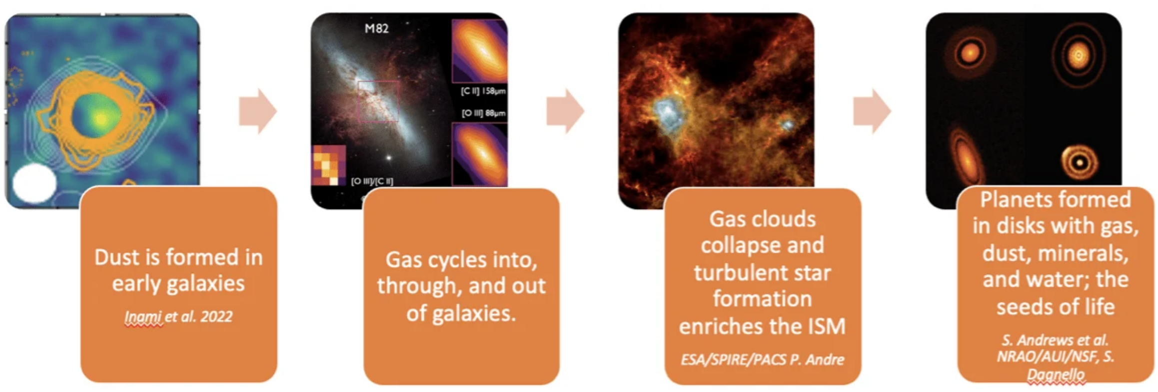
The PRobe far-Infrared Mission for Astrophysics -- PRIMA -- is an observatory concept being developed to address timely and fundamental questions about the growths of galaxies and solar systems and their constituents. It will observe the build-up of heavy elements, dust, stars, and black holes in galaxies, and trace the masses and water contents of protoplanetary disks to probe the growths of solar systems. The majority of the observing time will be devoted to General Observer (GO) programs. The PI programs will address key science with rapid releases of data to inform community GO planning and will yield rich archival datasets from surveys for community investigations. PRIMA will have spectral, hyperspectral imaging, and polarimetric capabilities, enabled now for the first time by extraordinary progress in detector array technology over the last two decades.

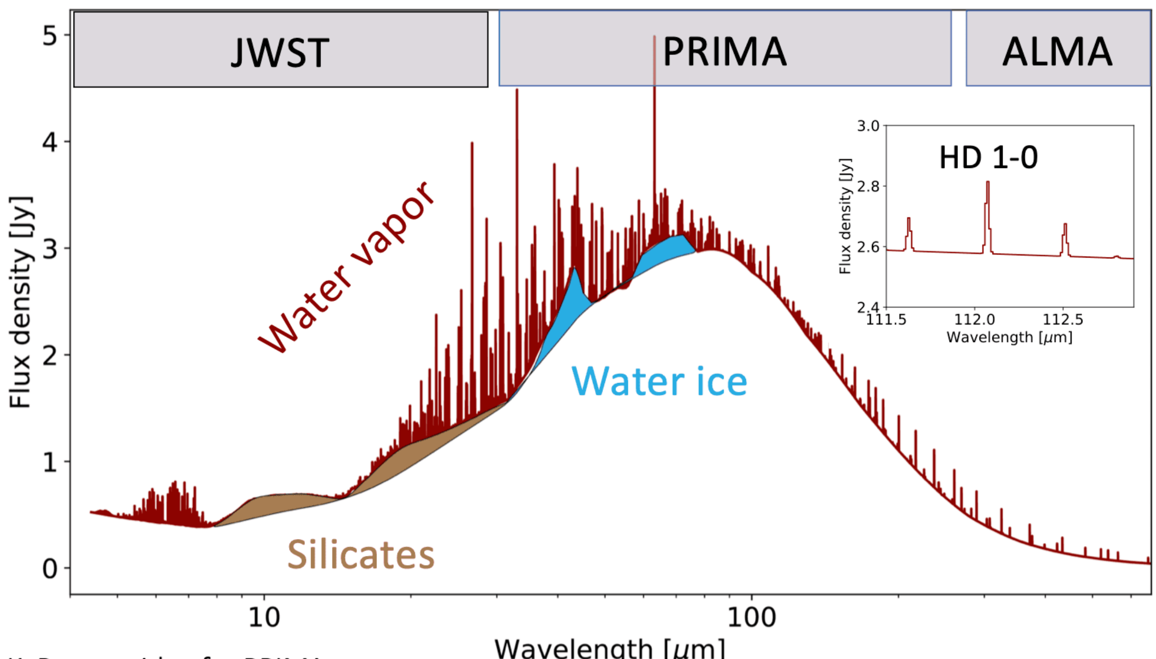
THE OBSERVATORY



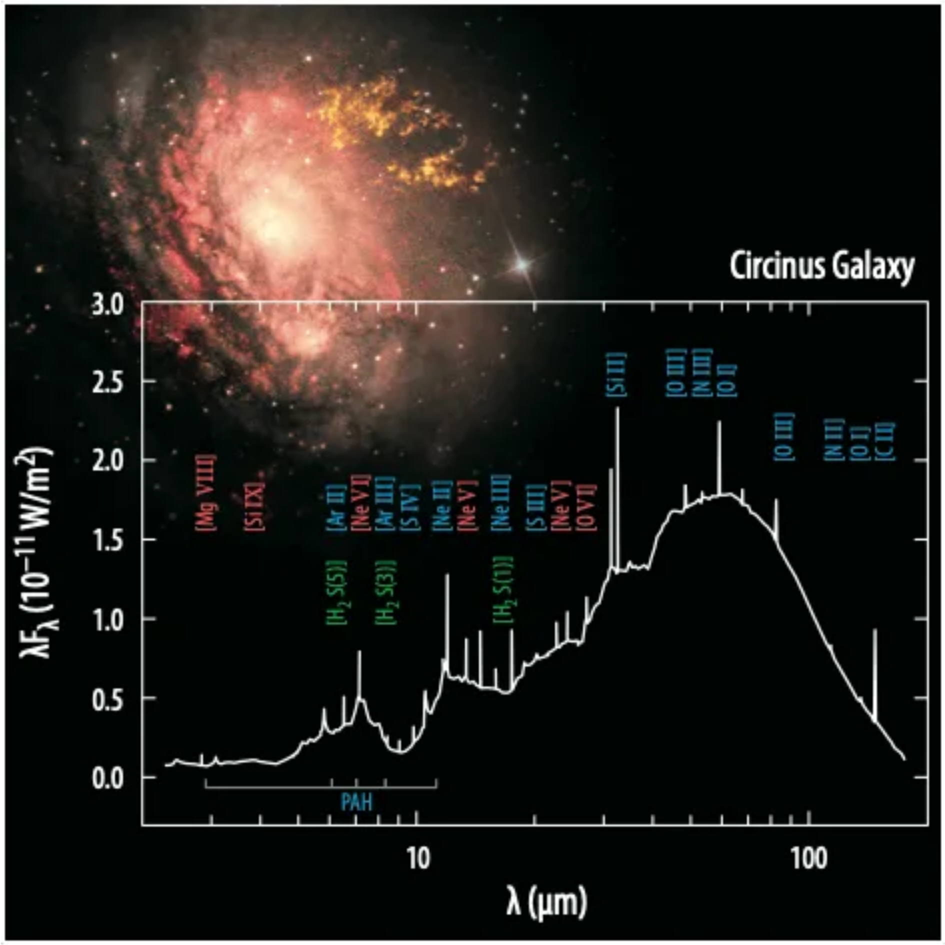
PRIMA's highly capable payload is designed to address key scientific questions and it will enable a broad range of community-driven science. With a 2-meter primary mirror and optics actively cooled to 4.5 K, it will make observations spanning wavelengths of 24 to 240 μm, filling most of the underexplored gap between JWST and ALMA. PRIMA's scientific payload takes maximum advantage of the cooled telescope by utilizing arrays of ultra-sensitive kinetic inductance detectors to be operated at a 100 mK base temperature. This will enable sensitivity near the astrophysical photon background limit arising from the zodiacal light at short far-infrared wavelengths and Galactic dust emission at the longer wavelengths. A four-module diffraction grating spectrometer will have a spectral resolving power of approximately 170 across the entire wavelength range for observations of atomic fine-structure lines, molecular lines, and solid-state bands. A Fourier Transform spectrometer will enhance resolving power – up to 4,400 at 112 μm – for separation of densely spaced H_2O lines and HD lines in protplanetary disks and resolution of galactic nuclear outflow emission and absorption lines for kinematic studies. Large galaxy surveys will be enabled by the PRIMAger: PRIMA's hyperspectral imager with a resolving power of 10 from 25 to 80 μm and broadband imaging from 80 to 264 μm. Galaxy redshifts will be determined from polycyclic aromatic hydrocarbon emission bands to probe dust and star formation across cosmic noon and into the early universe. The long-wave broad bands will be polarization sensitive for observations of interstellar magnetic fields and to make unique measurements of dust grain composition.

PRIMA SCIENCE





K. Pontoppidan for PRIMA



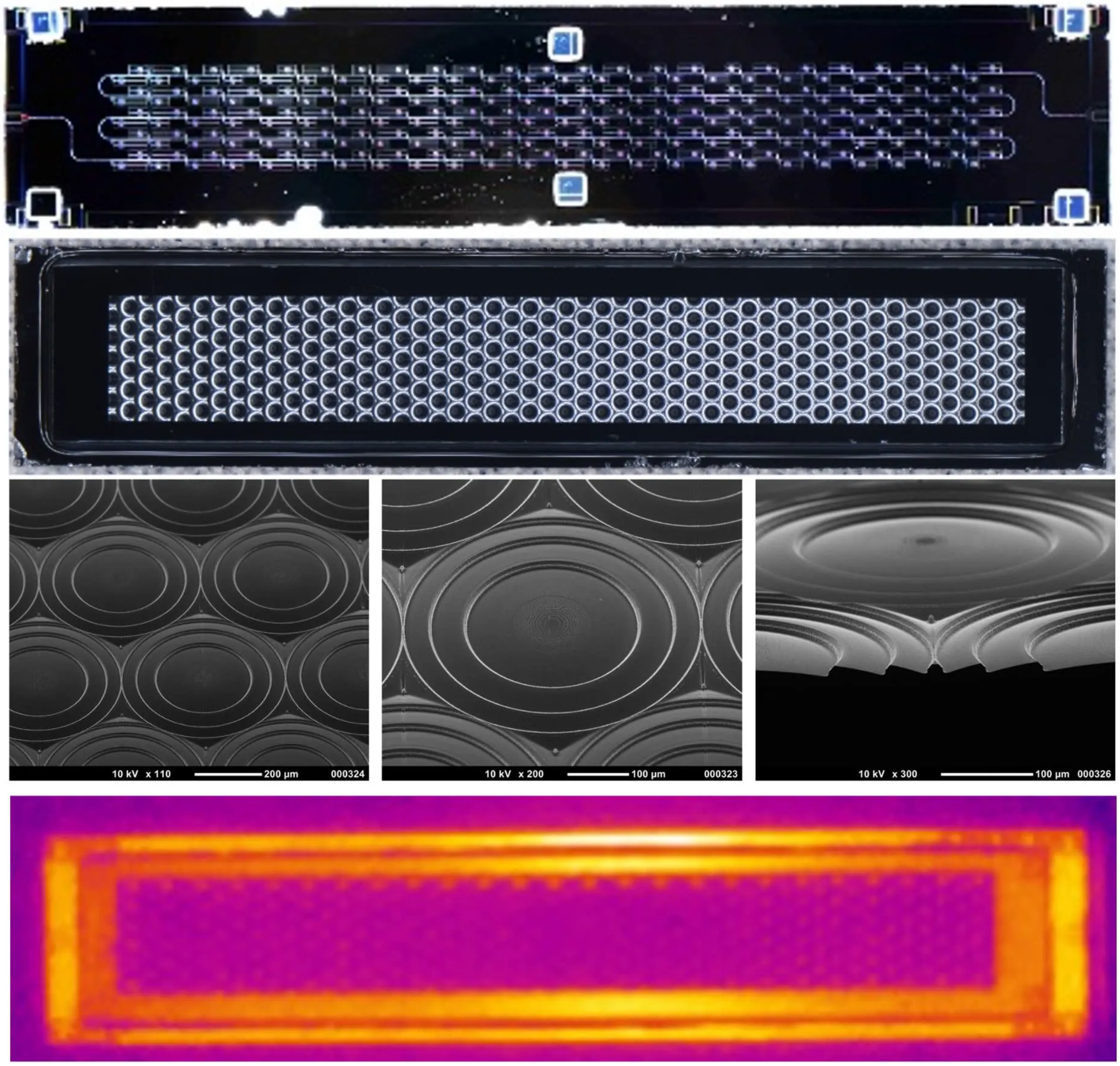
By accessing wavelengths beyond the reach of JWST and with revolutionary sensitivity, PRIMA will reveal how abundant atomic elements were built up from the primordial hydrogen and helium of the early universe and follow them as they form dust, provide cooling pathways to enable star formation and black hole growth, and become the molecular building blocks of new planets like our own (top panel). PRIMA will achieve this with its unique far-infrared eyes that see through the obscuring dust to reveal the contents and underlying physics of the Universe's most deeply embedded sources.

Understanding how planetary systems were assembled from the star formation processes is an ambitious scientific goal for the first half of the 21st century. PRIMA is being designed to help realize this goal with far-infrared spectroscopy of HD to measure protoplanetary disk masses, H_2O water vapor lines and ice emission bands to determine the distribution of water throughout protoplanetary disks, and bands of other solid-state features to measure mineralogy (middle panel).

The far-infrared spectrum is rich in features that hold clues to the physical processes that drive galaxy evolution (bottom panel, from the Origins study report). For example: the broad dust spectral energy distribution reveals star formation rates, high ionization state atomic fine-structure lines identify active galactic nuclei and their brightnesses correlation with supermassive black hole accretion rates (Stone, et al. 2022), lower-ionization lines probe star formation and metallicity, and bright emission bands from polycyclic aromatic hydrocarbons yield redshifts and trace the growth of metals over cosmic time (Li 2020). With its unprecedented far-infrared sensitivity, PRIMA will extend observations of the spectral signatures from bright local galaxies to the high-redshift universe.

The potential of PRIMA's enormous discovery space will be realized by the community through the General Observer program, which will comprise approximately 80% of the observing time spread over the five-year duration of the mission.

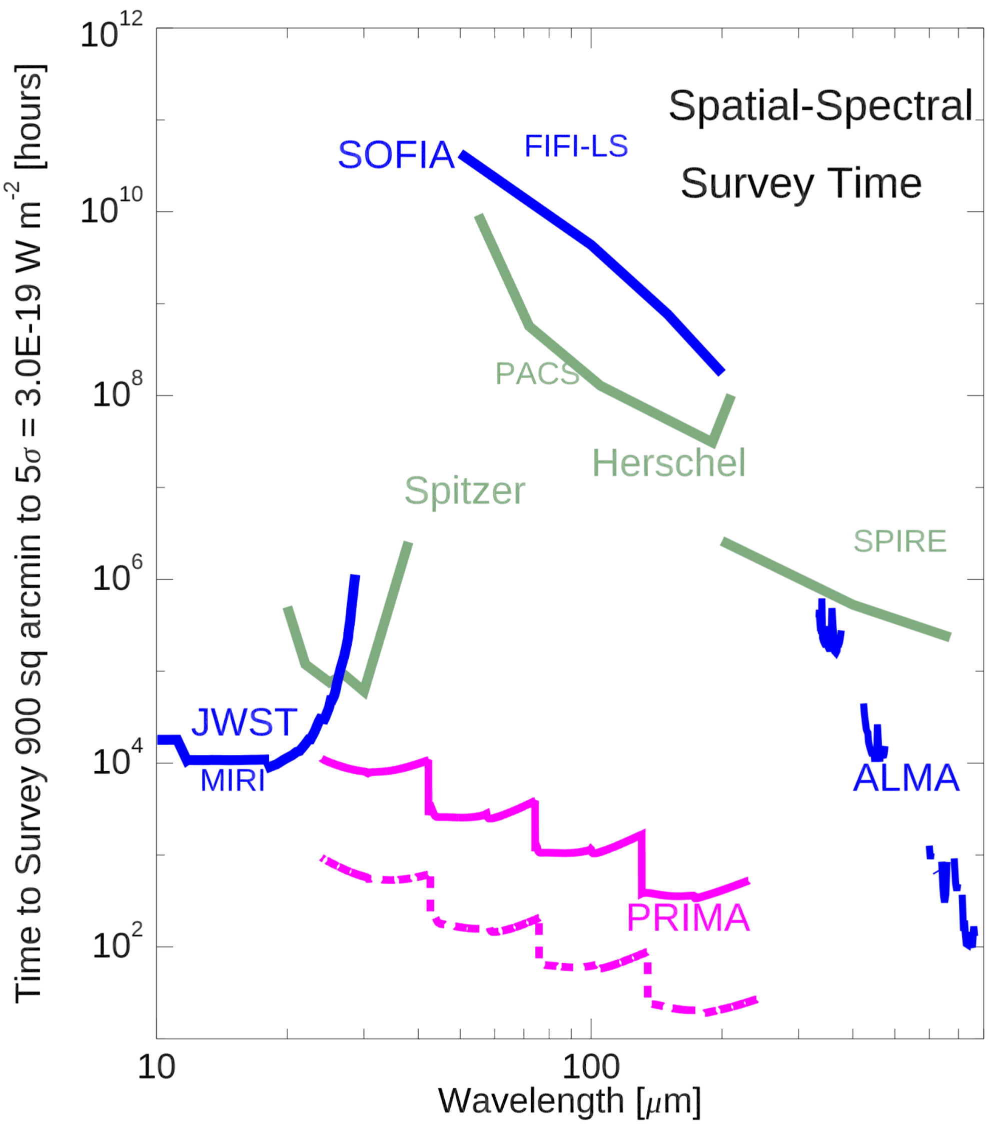
DETECTOR TECHNOLOGY

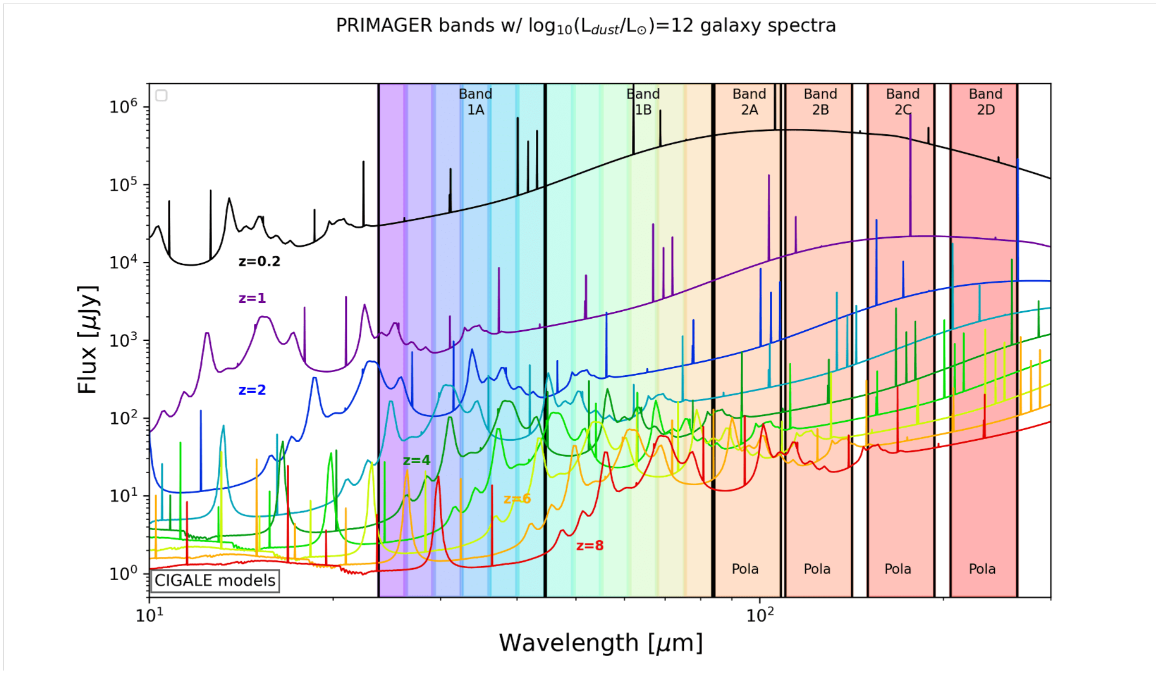


The key technological leap that enables the scientific advances to be made by PRIMA is development of large arrays of ultrasensitive superconducting detector arrays. Because of their simplicity of fabrication and elegant readout scheme that holds the complication at room temperature instead of cryogenic temperatures, PRIMA will utilize kinetic inductance detectors (KIDs; Day et al. 2003). KIDs are high quality-factor microresonators comprised of inductor-capacitor pairs, with each KID in an array designed for a unique readout frequency. Multiplexing factors of order 1,000 KIDs per coaxial cable pair and amplifier are possible. The top panel is a photograph of a PRIMA prototype KID array for 25 µm (the chip is approximately an inch in length).

Radiation is concentrated onto the absorbing elements via silicon microlens arrays. The second panel from the top is a photograph of a silicon microlens array fabricated by grayscale lithography. A zoom-in photograph of the lenses – Fresnel lenses – are shown in the third panel (the pixel pitch is 500 µm). The bottom panel is a mid-infrared image of a pair of bonded microlens and KID array chips. The uniform coloring shows complete filling of the gap by epoxy with no inclusions.

SPECTRAL COVERAGE





With both its spectrometer and imager, PRIMA aims to cover much of the spectral gap between JWST and ALMA, and to reach far-infrared sensitivities far beyond what was possible with previous technologies. The top panel compares PRIMA's long-slit spectrometer time to spectrally map a square degree of sky to previous and current observatories. The solid magenta top line is PRIMA's baseline speed and the dashed line is the goal speed. While there are currently no operational or planned observatories in this spectral range, PRIMA improves spectral mapping speed many orders of magnitude beyond previous observatories in this waveband.

The bottom panel illustrates the spectral coverage of PRIMA's imager, the PRIMAger. Shown are a model minimal ULIRG (ultra-luminous infrared galaxy) spectrum at various redshifts with PRIMAgers bands superimposed. From 25 to 80 µm, PRIMA will utilize linear-variable filters with a spectral resolving power of 10, sufficient to use polycyclic aromatic hydrocarbon emission bands from 3 to 17 µm rest frame (and silicate absorption at 10 µm rest frame) for galaxy redshift measurements. Coverage will extend to 264 µm with broad bands for spectral energy distribution measurements of galaxies and the dusty Galactic interstellar medium.

ABSTRACT

PRIMA is a far-infrared observatory concept being developed to address timely and fundamental questions about the growths of galaxies and solar systems and their constituents. It will observe the build-up of heavy elements, dust, stars, and black holes in galaxies and their interrelationships, and trace the masses and water contents of protoplanetary disks to probe the growths of solar systems. The majority of observing time will be devoted to Guest Observer programs to enable the astrophysics community to identify and plan the most critical observations, with focused PI programs to address key science with rapid releases of data to inform community planning. PRIMA will have spectral, hyperspectral imaging, and polarimetric capabilities, enabled now for the first time by extraordinary progress in kinetic inductance detector (KID) array technology over the last two decades. The 2.0-meter telescope will be cooled to < 5 K to take maximum advantage of the KID sensitivities. For observations of atomic fine-structure lines, molecular lines, and solid-state emission and absorption bands, R = 200 spectral coverage will range from approximately 25 μm to 200 μm, with a high-resolution mode across the entire band that will have a spectral resolving power of a few thousand at 100 μm. R ~ 10 moderate-resolution (hyperspectral) imaging will range from 25 to 80 μm for rest-frame, mid- and far-infrared spectral energy distribution measurements to probe dust grain composition and disambiguate star formation and active galactic nuclei in galaxies. Polarimetric observations of large areas of Galactic molecular clouds and the Magellanic Clouds from 80 to ~200 μm will bridge between the large-scale polarimetry of the interstellar medium from cosmic microwave background observatories and protostellar disk-scale interferometric observations to probe magnetic fields at the critical scales at which clouds collapse to form stars. An overview of PRIMA's basic design and capabilities will be presented. Other posters in this session describe PRIMA science, technology, and instrumentation in greater depth.

REFERENCES

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